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DEVELOPMENT AND FABRICATION OF A POLYCARBONATE EYESHIELD FOR THE U.S. ARMY FLYER'S HELMET

by

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UNITED STATES ARMY
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Clothing & Personal Life Support Equipment Laboratory
C&PSEL-76

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AD _____

TECHNICAL REPORT

71-3-CE

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June 1970

Clothing and Personal Life Support Equipment Laboratory
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts

FOREWORD

In it continuing efforts to provide the American soldier with
efficient protective combat clothing, the U. S. Army Natick Labora-
tories often tries to exploit a new material that has desirable pro-
tective characteristics, but cannot be used because it appears unsuitable
for processing by normal procedures. Polycarbonate resin was such a
material. Despite its transparency and high impact resistance proper-
ties, it could not be made optically acceptable for eyeshields. This
was especially true in relatively large complex curves (toric).

In this report, the development and fabrication techniques of an
optically acceptable polycarbonate eyeshield for the U. S. Army's
Flyer's Helmet are discussed. The information contained is a history
of a research and development program and should be considered as a
reference only and not as an absolute method of producing polycarbonate
eyeshields.

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ABSTRACT

The need to provide U. S. Army aircrewmen with increased eye protection saw a production technique developed to make optically acceptable, shatter- and impact-resistant eyeshields from polycarbonate resin. It was found that production quantities of optically transparent polycarbonate lenses can be manufactured with a great deal of reliability by injection-molding processes. Injection-molding of polycarbonate lenses employs standard equipment and techniques. These, however, must be adjusted to account for the idiosyncrasies of the resin, e.g., hygroscopic and flow characteristics.

In this fabrication project, the mold used was end-gated and highly polished. Of three available grades of resin, the material with the lowest molecular viscosity provided the best results. The development molds produced about 75,000 acceptable eyeshields which were made available to U. S. Army and Air Force airmen for immediate tactical use.

The polycarbonate resin characteristics and molding techniques that influenced the design of the eyeshield, and the development of the fabrication technique are discussed. Also discussed are factors that governed the selection of material type, mold design, and quality assurance considerations.

DEVELOPMENT AND FABRICATION OF A POLYCARBONATE EYESHIELD FOR THE U. S. ARMY FLYER'S HELMET

1. Introduction

The U. S. Army is engaged in a continuous research and development program to provide maximum head protection to the aircrewmen against all hazardous and climatic environments. Each new technological development is scrutinized to determine if it may, in any form, satisfy or up-grade protective requirements for the combat soldier. It was in this context that polycarbonate resin was investigated for possible use in protecting the eyes from impinging fragments. Besides resisting shattering and penetration by fragments, the eyeshield used by aircrewmen should not spall when impacted and, in addition, must provide protection against sunglare and flash fires. Many transparent plastics were previously evaluated against these requirements; each was rejected because of deficient physical properties, unsatisfactory optics, or production difficulties.

The standard eyeshield used to protect the eyes against sunglare, windblast, and flash fires is made from acrylic resin. This material is easily formed into many lens shapes which provide excellent optics. Acrylics, however, are relatively brittle and will shatter somewhat like glass when they are impacted. A requirement for protecting the eyes against impacts and impinging fragments could not be satisfied by acrylic resin in the thickness that is used for the eyeshield (about 0.080-inch). Yet medical statistics report that many facial and eye injuries result from either primary or secondary fragments or from shards or spall generated from impacted acrylic shields.[1]

Initial investigations of polycarbonate resin revealed that this plastic would not shatter or spall when exposed to a ballistic-type, low-mass, high-velocity impact. Although the earliest polycarbonate resins evaluated exhibited poor color and could not be considered suitable for an optical device, industry was encouraged to improve the optical characteristics of the resin because of its potential protection capabilities.

The exploitation of polycarbonate resin resulted in a reduction of its amber color first to light yellow, and then to a tinge of straw color. Transparent polycarbonate resin, with good color, is readily available in sheet form and is also available as molding pellets which can be molded into transparent shapes. Optically transparent or optically acceptable lens of polycarbonate resin, however, were still outside the state-of-the-art.

Primary efforts for making polycarbonate lenses or eyeshields were concerned with a thermo-forming method which started with an extruded sheet. These techniques did not yield successful results because the quality of optics obtained was limited to that of the extruded sheet. Because of the nature of the manufacturing process, these sheets contained variations in thickness, striae, and other inherent flaws and stresses which introduced optical aberrations in a lens.

Casting operations were considered necessary to eliminate inherent faults and make a polycarbonate eyeshield with desired optical characteristics. Since casting of polycarbonate resin was outside the present state-of-the-art, "casting" had to be interpreted in the broadest sense. Liquid polycarbonate could be poured between parallel surfaces under high heat and pressure. This suggested injection-molding. Optics of an injection-molded lens would then depend on parallelism of the mold, physical characteristics of the mold's surfaces and controlled shrinkage in the mold.

In conjunction with the Mine Safety Appliances Company*, the U. S. Army Natick Laboratories developed an injection mold and the processing technique to make a polycarbonate eyeshield for the U. S. Army Aircrewman's Helmet.

2. Eyeshield Design

The configuration and critical dimensions of the standard large-size acrylic eyeshield were retained. The same shape eyeshield is also used by the U. S. Air Force in its large-size HGU-2A/P Flight Helmet. Except for the lower edge, the contours of the eyeshield are similar to those used with the Navy's large APH-6A flight helmet.

The standard eyeshield is made from methylmethacrylic resin and requires five operations to fabricate:

 a. Casting optical grade sheets

 b. Thermo-forming or blow-molding the lens

 c. Trimming and finishing the lens

 d. Molding eyeshield guides

 e. Adhering guides to the eyeshield

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* Contract DA19-129-AMC-332

By injection-molding a polycarbonate resin eyeshield with integrated guides, the number of fabricating operations was reduced to two: molding, then trimming and finishing.

To make the eyeshield with integral guides, a redesign of the guides was necessary to obtain a molding without undue internal stresses. A continuous guide similar to that in the standard acrylic eyeshield would have presented difficulties in filling the mold and would present a potential shrinkage problem. To overcome these difficulties, the guides were split into two bearing surfaces, one on each end of the eyeshield edges (Figure 1). The split guides were grooved along their length to reduce their bulk, thereby reducing the probability of distortion due to differential shrinkage of heavier sections. The critical dimensions and bearing surfaces of the split guides were not changed from those of the older continuous guides (Figure 2).

3. **Mold Design**

A single-cavity injection mold was designed with fan-gating on one end and a conical runner (Figure 3). The mold was made to produce one eyeshield with the intention of adding a second cavity and force during the development program (location of gate precluded a balanced set-up of the mold), thus requiring a counterweight which was built as part of the mold (Figure 4). The size of the mold base dictated the size of the machine to be used. The only machine available with the required platen size was a 20-ounce, 450-ton injection molder. It was ultimately determined that a single-cavity mold could be made smaller and lighter, but not in the current design. The current mold design, even with a single cavity, would require it to be counterbalanced in the machine.

Two molds were made. The first was designed and used successfully until it broke under pressures of production. Benefiting from this experience, a second mold with a single cavity was made.

The first set of mold inserts (cavity and core) were made from 420 cast stainless steel hardened to 40-50 Rockwell "C". Although a substantial number (about 25,000) of eyeshields were produced and the mold was subjected to a total of about 60,000 shots, it did exhibit a number of shortcomings. The cast mold surface would not take a suitable polish for polycarbonate optical moldings.[2] The ability to retain a polish is an important characteristic for mold steels, especially so for polycarbonate resin because it will faithfully transfer the mold surface to the lens. The mold surface also stained or somehow reacted with a residue from the polycarbonate resin. Periodic polishings were required to remove the stains and to maintain a clean, smooth surface. This resulted in excessive down time that would be considered prohibitive during production.

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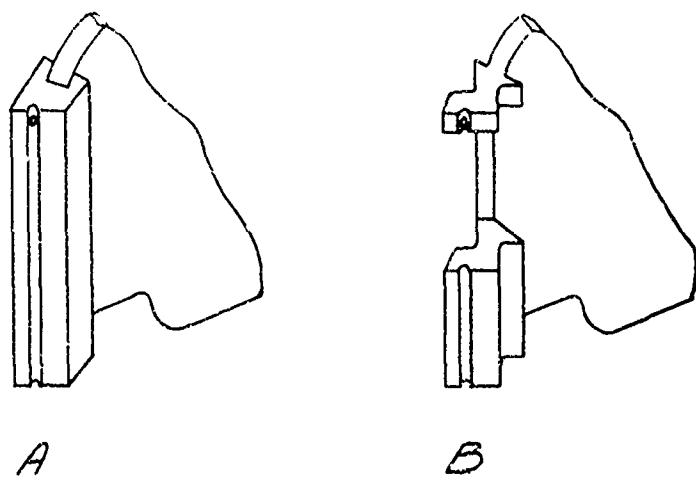
Figure 1. A. Acrylic eyeshield guide cemented to eyeshield.

B. Polycarbonate eyeshield guide molded as an integral compoennt of the eyeshield.
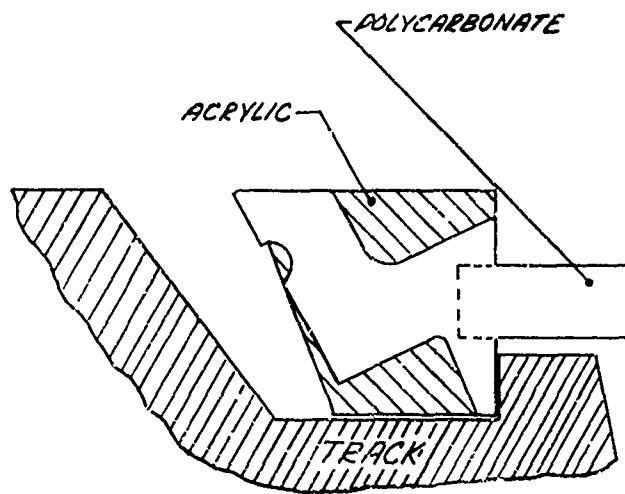
Figure 2. Cross-section: Polycarbonate eyeshield guide and acrylic eyeshield guide inserted into eyeshield track.
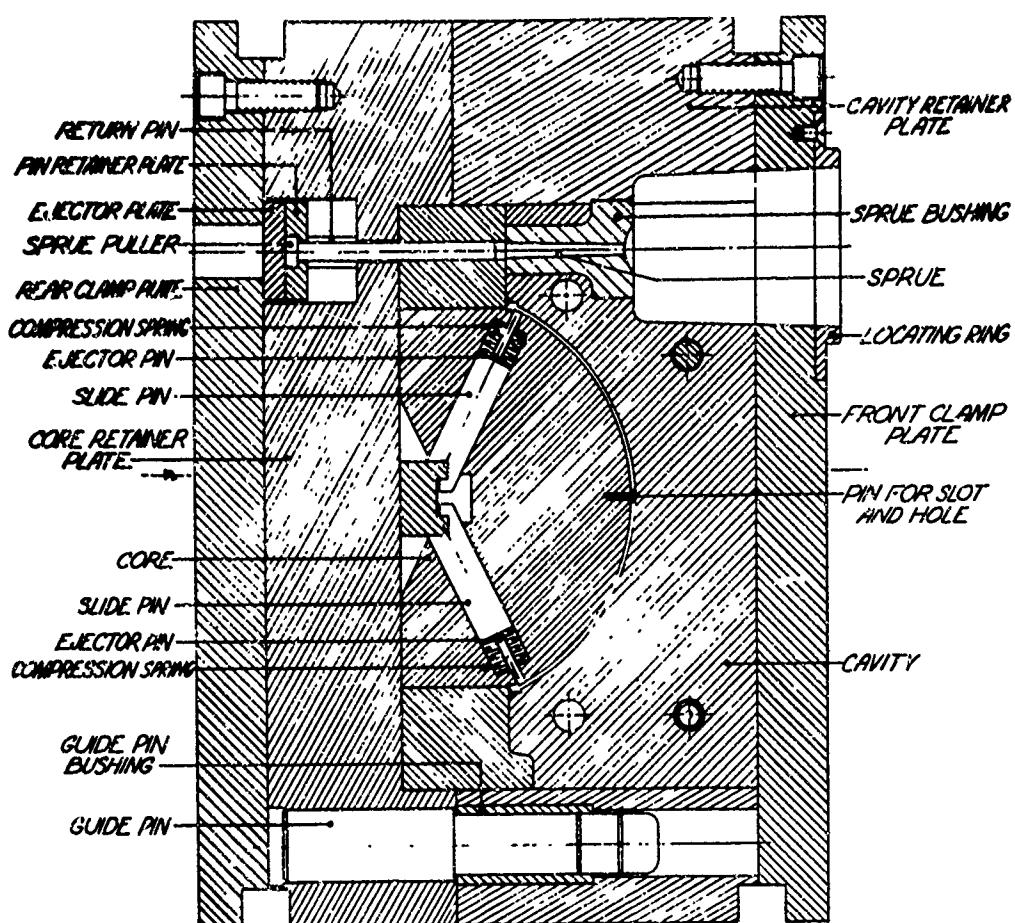
Figure 3. Diagram of first developmental mold to produce
optically acceptable polycarbonate visors
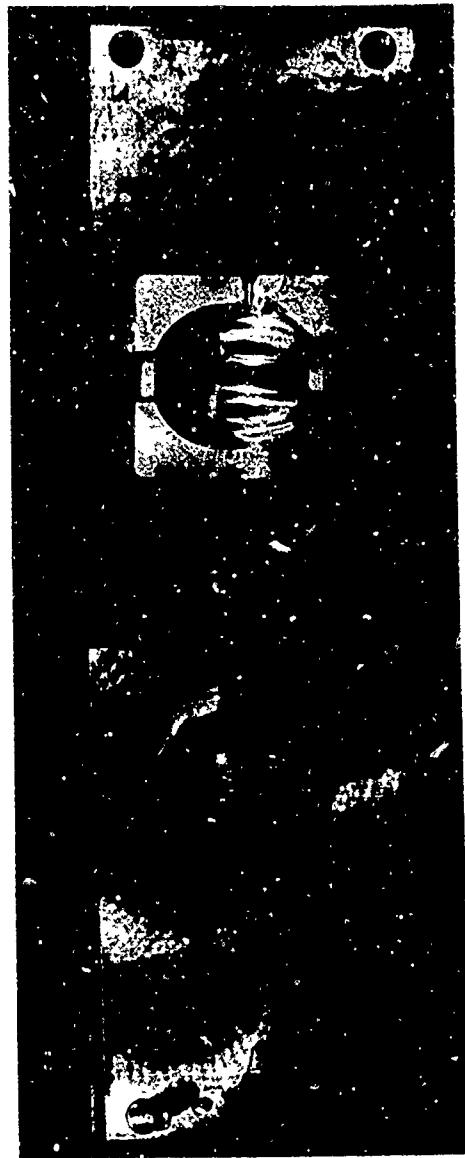
Figure 4. Opened stainless steel mol. (first production mold for making polycarbonate eyeshields) showing the massive counterweight, the single cavity and the provisions for a second cavity

The multiple polishing of the mold emphasized the importance of the surface finish and the relative degree of smoothness required. With each successive polishing, the optical distortion exhibited by the eyeshield was reduced, thereby confirming that distortion, the only apparent optical deficiency encountered, was due to surface optics and could be corrected.

To increase productivity by reducing the need for frequent polishings, the cast stainless steel mold surfaces were chrome-plated. This finish permitted cleaning of surfaces while the mold was in the machine. After about 60,000 shots and about 25,000 acceptable eyeshields, the stainless steel mold developed hairline cracks which could not be polished out.

A second mold was made. This mold was designed to overcome short-comings of the cast stainless-steel mold. It was a conventional mold base and inserts were made from forged H-13 steel, a deep air-hardening steel which will harden throughout a rather large cross-section. [3] The insert surfaces were plated with a nickel alloy to protect the mold surfaces from corrosive residual products and to permit easy cleaning.

Ejection of the eyeshield from this mold was accomplished with only three straight knockout pins, one on the sprue which formed the apex of a triangle and the other two forming the base on the fan gate at its junction with the eyeshield.

Polycarbonate resin has the quality of faithfully duplicating the mold surface. It is, therefore, mandatory to attain a surface (polished as perfectly as possible) to reduce the degree of optical aberrations caused by surface imperfection. No surface finish standard has been established; inadequate polishing would result in deficiencies that would probably manifest themselves as distortions which could, however, be minimized as the surface finish is improved. Plating the surface, whether it is done with chrome or nickel, will not necessarily improve the finish. Plating will only make the mold surface durable, and may serve to magnify inherent surface defects.

Both halves of the mold are channeled so that the mold tempera-ture may be maintained by circulating water. The mold is end-gated with a fan gate. This is the recommended conventional type of gate designed to mold thin-walled, long-edged items like the eyeshield. A typical mold design used to make the eyeshield is shown in Figure 3.

4. **Material Selection**

At the time of this development, there were only two major producers of polycarbonate resin in the United States. Each manufacturer produced three grades of resin. These resins may be classified as having high,

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medium, and low melt viscosities. The melt viscosities of each manufacturer's product were similar; the physical properties of the three grades of resins of both manufacturers were also similar. Each of the resins may be categorized by its flow length as determined by ASTM Designation: D1238-62T, "Measuring Flow Rates of Thermoplastics by Extrusion Plastometer". Table I shows the average expected flow length of the three grades of polycarbonate resin.

TABLE I

FLOW RATES OF POLYCARBONATE RESINS AS DETERMINED BY THE EXTRUSION PLASTOMETER

Melt Viscosity	Flow Length
High	6 inches
Medium	6.5 to 8 inches
Low	8.5 to 10 inches

The flow length of the eyeshield, including the end-gating system, is 10.5 inches. It may be predicated that the low melt-viscosity resin should just about fill the mold (Table I). The results of actual molding trials with each of the three type resins (Table II) confirmed the conclusion derived from the plastometer tests that low melt viscosity resin would be best suited for making the eyeshield.

TABLE II

FLOW RATES OF POLYCARBONATE RESINS AS DETERMINED BY MOLDING EYESHIELDS

Melt Viscosity	Flow in Mold
High	Mold not filled completely
Medium	Mold filled but required long injection time and high temperatures that caused scorching of the eyeshield
Low	Mold filled satisfactorily

An investigation was made to determine the factors, other than melt viscosity, wherein the three grades of resin differ. With this information, it was anticipated that a resin or blend of resins might be developed which would have improved molding and physical characteristics. It was

also expexted to provide a means of varying the resin characteristics required to satisfy specific needs. One resin manufacturer provided injection-molded test samples which consisted of .080-inch-thick tensile test samples and 4-inch diameter discs made from each grade of resin. Specific data regarding each grade of resin (Table III) were also provided.

TABLE III

PHYSICAL PROPERTIES OF POLYCARBONATE RESIN

Relative Melt Viscosity	Molecular Viscosity	Molecular Weight	Molecular Number	1/4-Inch Izod Impact	Glass Transition Temperature
Low	1.30	31,200	16,000	2.3	152 C (305.6 F)
Medium	1.33	34,100	16,500	3.0	154 C (309.2 F)
High	1.36	38,200	17,100	3.0	156 C (312.8 F)

Tensile tests of the prepared samples showed no difference in the stress-strain curves among each type resin (Figure 5). After annealing the samples at 220F for 24 hours, testing resulted in an approximately 10 percent uniformly increased value in the stress-strain characteristics of the resin.

High-velocity impact testing was conducted by shooting .22 caliber, 17-grain fragment simulators at the injection-molded polycarbonate discs to determine their V-50 ballistic limit. (The V-50 ballistic limit is the impact velocity at which the probability of penetration of a material by a test projectile is 50 percent).[4] Also determined was the V-0 ballistic limit, that is the highest impact velocity of a fragment simulator at which there is no probability of penetrating a sample nor generating spall. The presence of spall was determined by noting if there were perforations in a 2-mil-thick aluminum foil witness plate set 2 inches behind the target. In the study, as in the tensile strength test, all three resin types reacted similarly. Annealing of the test samples resulted in approximately 8 percent increased resistance of fragmentation penetration (Table IV).

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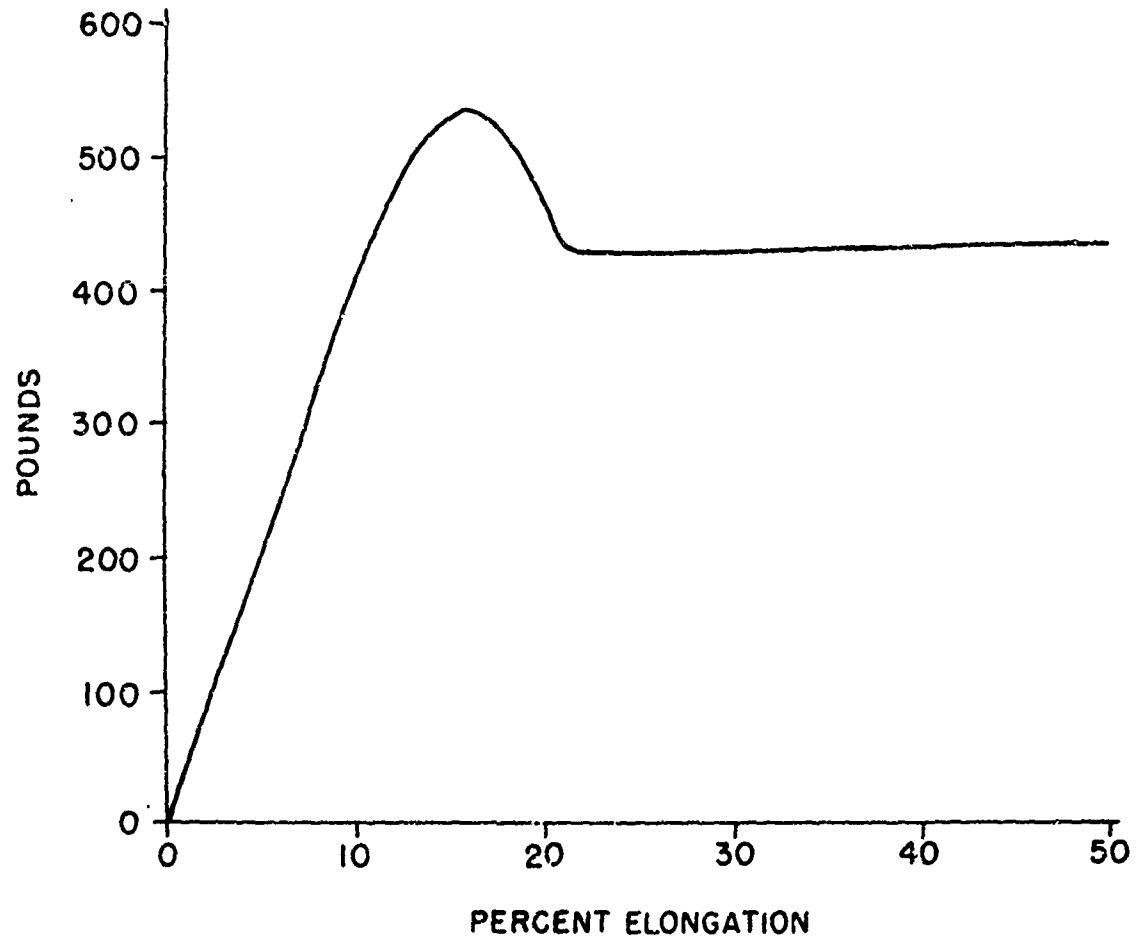
Figure 5. Typical stress-strain curve for molded polycarbonate
plastic using low, medium or high melt viscosity resin

TABLE IV

BALLISTIC LIMITS (FEET PER SECOND) OF POLYCARBONATE RESIN

Melt Viscosity	V-50		V-0	
	Normal	After Annealing	Normal	After Annealing
Low	555	604	550	600
Medium	572	620	560	610
High	564	611	560	595

Clear polycarbonate resin normally molds into a light straw or light yellow tint. To eliminate this coloring, moldings were made incorporating a light blue dye and an ultraviolet stabilizer. These blue-tinted moldings appeared to be clearer, but did, in fact, transmit less light than did the natural resin. Table V shows the average percent light transmission values through natural and tinted 130-mil-thick polycarbonate plaques.

Neutral gray-tinted visors are required for sunglare protection. Several dyes were molded into the visors and were evaluated. There was little difference in chromaticity and light transmittance characteristics among the materials. The selection of the dye for making neutral gray eyeshields depends on the fabricator's choice of a dye that would satisfy specified requirements. A variation in thickness of the visor will cause a variation of the percent light transmission through a neutral gray eyeshield.

TABLE V

EFFECT OF TINTING ON CLEAR POLYCARBONATE RESIN TO ELIMINATE NATURAL COLORING

Resin	Percent Luminous Transmittance
Natural	84 to 86
Tinted	76 to 78

5. Material Processing and Molding

Polycarbonate resin absorbs relatively small quantities of moisture under normal service conditions (less than .05 percent water is absorbed as a result of immersion). To obtain satisfactory molded parts, however, it is essential to use dry resin. Prior to molding the eyeshield, the polycarbonate resin pellets were stored in a drying oven at 250°F for six hours. They were then loaded into the injection-molding machine's drying hopper which was maintained at a temperature of 200-250°F. Great care was taken to assure that the resin was not contaminated. If the resin should be inadequately dried, the resulting moldings might contain streaks or bubbles or appear misty. Moisture in the resin might also cause embrittlement of the molding or significantly reduce its impact strength.

Conventional equipment and techniques are used in the injection-molding of polycarbonate eyeshields. Molders using standard injection-molding machines and processes should not encounter serious problems. They must, however, treat polycarbonate resin as an entity, adjust to the material's idiosyncrasies, and try not to identify it with other resins. Injection-molding of polycarbonate resins requires higher temperatures, higher pressures, and shorter injection times than is generally associated with other resins.

Because of the size of the mold used for this development, a 20-ounce, 450-ton injection-molding machine was used (Figure 6). With a properly designed, single-cavity mold, it is thought possible, however, to use a 5-ounce, 200-ton molding machine. Molding parameters used for this development are shown in Table VI.

In the discussion of materials, it was shown that the maximum flow length that could be expected from the low melt-viscosity resin is 10 inches (Table I). The length of the eyeshield mold approaches the maximum expected flow length. This mold includes the eyeshield, gate and runner. Because the mold must be filled over a critical length, the injection operation is sensitive. The polycarbonate melt must be kept in a fluid state at the highest possible temperature without burning or scorching.

The temperature of the melt is controlled by heating chamber temperatures, screw speed, and length of time in the heating chamber. It appears that the most critical of these three variables is the length of time (residence time) in the heating chamber.

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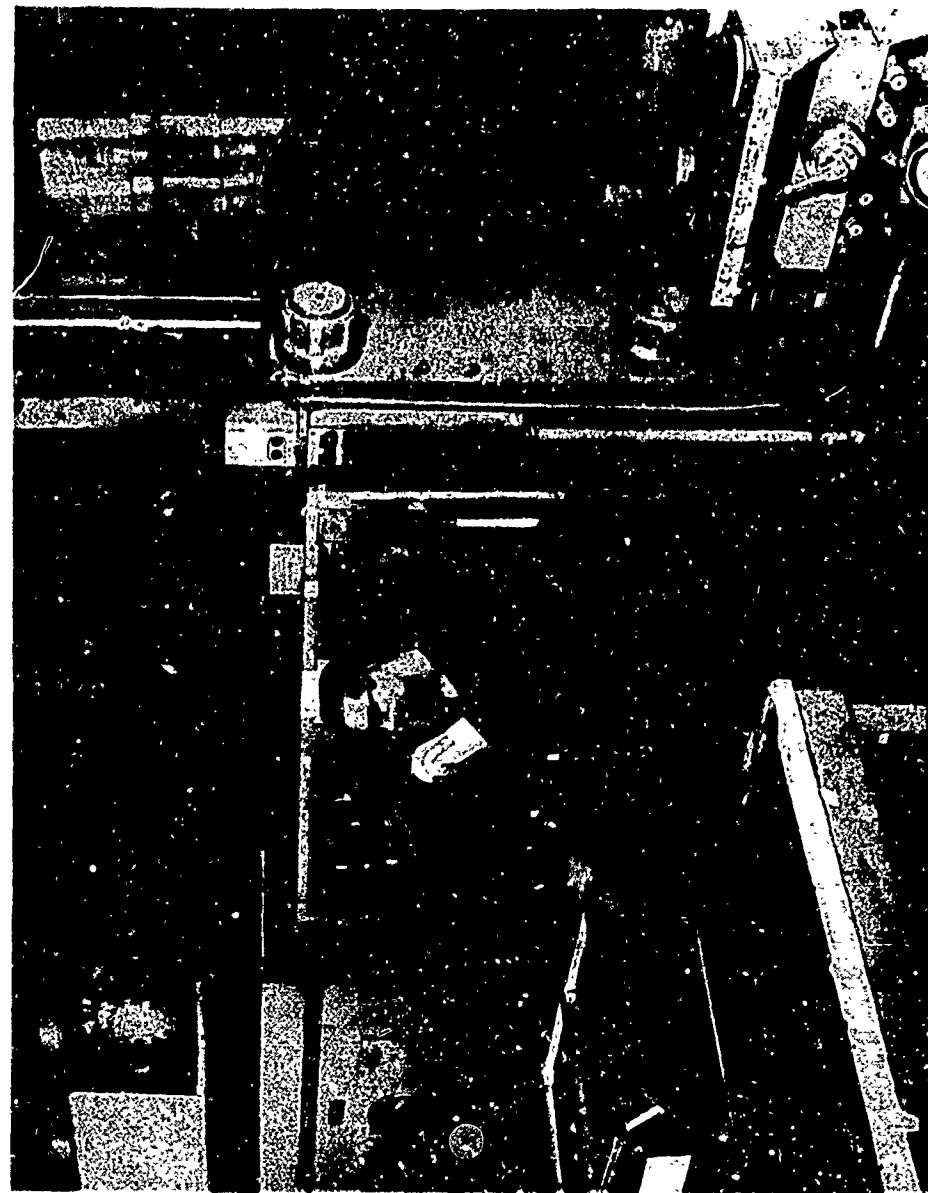
Figure 6. Initial inspection of eyeshield is made by the machine operator at the 20-ounce, 400-ton injection molding machine

Residence time is determined by the number of shots in the chamber. Only a 2-1/2 ounce shot is required to fill the eyeshield mold while the heating chamber of the 20-ounce machine used for this development stored 15 ounces of resin. Each shot had, therefore, been in the heating chamber for six heats. The length of this residence time and the variations due to press "open time" make temperatures difficult to control. Unless these variables are adequately controlled, molding will result in short shots and burned shots.

Because of the long residence time, cycle time also becomes a critical consideration. The size of the mold precluded the use of a smaller injection-molding machine, thereby reducing the residence time. Nevertheless, with an understanding of the process and careful control of the variables, satisfactory eyeshields were manufactured.

The finishing operation starts at the injection-molding machine. The operator, after removing the visor and making an initial inspection for obvious deficiencies (Figure 6), removes the sprue, the gate and flash (Figure 7). The visor then moves to another station where the sharp edges are broken. This operation was troublesome and was not brought to production efficiency at the completion of the development effort. All visor edges were either scraped, filed or honed. Mechanized attempts to break the edge of the visor seemed to push or flow the resin thereby creating an undesirable burr.

TABLE VI

MOLDING PARAMETERS

Cylinder Temperatures

1A Adapter	670-700 F.
Front	650-680 F.
Center	650-680 F.
Rear	500-580 F.

Cycle

Full Injection	4-9 seconds
Injection Hold	7-14 seconds
Clamp	20-40 seconds
Mold Temperature*	140-180 F.
Injection Speed (one shot)	2-4 seconds
Screw Return Time	4-8 seconds
Screw Speed	20-50 rpm
Feed (travel of ram)	1-1/8 to 1-1/2 inches
Injection Pressure	
High	20,000 psi
Low	14,000-17,000 psi

* Outlet water temperature

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6. **Quality Control**

With each start-up and with each new batch of resin, molding conditions must be checked and, when needed, proper adjustments made to produce satisfactory eyeshields. From that time until the next start-up or new batch of resin, the resulting eyeshields should have a minimal change in their properties. Most defects in the eyeshields caused by deficient molding techniques were readily apparent to visual inspection. These defects are primarily:

   a. Discoloration or buring

   b. Short shots

   c. Contamination

The defects can readily be detected with the unaided eye by looking through the eyeshield, from a distance of about 12 inches, toward a lighted surface. Striae waviness, cloudiness, and other imperfections such as pits, bubbles, scratches, lint and other foreign particles not readily detectable by visual inspection can be detected by specification tests. [5, 6, 7]

If the defects are present and are not readily detectable by the specified tests, then it may be assumed that they will not affect the serviceability of the eyeshields.

Contamination can be reduced by good housekeeping and scrupulous care in handling of the resin from the time of its manufacture, receipt at the plant, to the final molding operation. Further reduction of contamination may be accomplished by proper purging of the injection-molding system and cleaning of the mold. Purging may not always be feasible; the machine should then continue operating until the contamination runs itself out.

Burning and short shots usually are the results of an inadvertent change in molding conditions or fabrication procedures. Visual inspection of each eyeshield removed from the mold would permit timely adjustment of the production operation to reduce the incidence of burning or short shots.

Brittleness of the eyeshield may also be an indication of deficient molding conditions. The brittleness test used for safety glasses [8] is to drop a 1.5-inch-diameter steel ball 50 inches onto the lens. The

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polycarbonate eyeshield did not fracture, crack, or craze as a result of this impact test even at temperatures ranging from 185°F to -40°F. The eyeshield was also impacted with an 8-pound ball dropped 48 inches and did not fail. Brittleness or potential brittleness of a polycarbonate eyeshield can be detected, however, by means of a high rate of loading impact, such as a ballistic impact.

The specification for the eyeshield requires that it withstand three 550 feet per second impacts, one in the center and one in each critical vision area, without cracking, penetration or spall. These impacts are made with a .22 caliber, 17-grain fragment simulator. [7] Cracking, spall, or punch-out at velocities of 550 feet per second or below could be an indication of a defective molding operation. This deficiency probably is caused by either an unevenly heated mold or a mold that is not hot enough to preclude undue stresses. By adjusting mold temperature and cylce, these stresses could be minimized, thereby reducing the incidence of brittleness failure.

All other defects are generally optical deficiencies. As previously stated, once operations are adjusted to produce satisfactory eyeshields, properties should not vary significantly until the machine is shut down, or possibly a new batch of resin is introduced. Any change in optical properties would indicate process or mold deficiencies.

7.   Discussion

As a result of producing an excess of 40,000 eyeshields with the two developmental molds and testing optical properties, the factors that would influence optical characteristics were determined.

Luminous transmittance, or total light transmission, is the ratio of visible light (electromagnetic energy wavelengths between 430 and 730 millimicrons) passing through the eyeshield to the total incident light. Light transmission can be affected first by the batch of polycarbonate resin being used, and then by the processing technique. Burning or discoloration of the eyeshield will significantly reduce the eyeshield's luminous transmittances. This characteristic was measured with a recording spectrophotometer. A chi square test was run on the date for "goodness of fit"; the data approximate a normal distribution adequate to permit the use of normal statistical techniques. The process capability of the polycarbonate resin for this phase of the development permitted an average light transmission of 88 percent with six standard deviations (S.D.), ranging from 82 to 94 percent. This range encompasses 99.86 percent of the specified production of eyeshields; 95.90 percent of the eyeshields exhibited 84 to 92 percent luminous transmittance.

Diffuse Transmittances, or haze measurements, were made by means of a recording spectrophotometer. A chi square test of the haze test data indicated that the data approximate a normal distribution. The eyeshields exhibited an average of transmittance of diffused light of 0.78 percent with a standard elevation of 0.45 percent. Thus, 99.86 percent (six S.D.) of the visors will exhibit haze readings between 0.0 and 2.13 percent. The primary cause of haze is the insufficient drying of the resin. Haze may also be caused by an inadequately polished mold surface.

Ultraviolet Transmittance is the total light transmitted through the eyeshield in the erythermal band of 250 to 320 millimicrons. Essentially, no ultraviolet light was shown to be transmitted within the capabilities of the spectrophotometer used for these measurements. This characteristic appears to be a function of the polycarbonate material. The molding process should in no way affect the ultraviolet transmittance. Testing for this characteristic may, with confidence, be conducted on a batch basis only.

Other characteristics affecting optics may be caused by physical defects in the eyeshield as opposed to the "optical" properties discussed. These deficiencies are concerned with the bending of light passing through the eyeshield. Three deficiencies may be collectively categorized as prismatic deviation:

    a. Vertical prismatic deviation

    b. Horizontal prismatic deviation

    c. Spherical and cylindrical power

Defects in these characteristics are virtually always a function of the mold. Distortion and haze may also be controlled by the mold, but to a much lesser degree.

Horizontal Prismatic Deviation is a shift in direction of the viewer's line of sight. This deviation may be present because of uneven forming or congealing of the resin. Nonparallel surfaces or variations thickness will also cause deviation of line of sight. This defect may be controlled by a well-designed mold with smooth parallel surfaces, uniform heating and/or cooling capabilities, and sufficient clamping pressure and suitable locks to keep the mold from separating or moving under high pressures.

Vertical Prismatic Deviation is a shift in position of the viewer's line of sight. This defect is also a function of material thickness. It is, in fact, the same as horizontal prismatic deviation, except for

the direction in which transmitted light is shifted. Vertical prismatic deviation is caused by the same factors that influence horizontal prismatic deviation and will undoubtedly be overcome with the same corrective actions.

Spherical and Cylindrical Power defines the curvatures of the eyeshield. This is solely controlled by the configuration of the mold. This is measured by determining the magnification present in each critical visual area of the eyeshield.

Distortion may be a function of the molding process; it may also be caused by a defective mold. Uneven heating and/or cooling causing striae or internal stress will cause distortion. The deficiency will also manifest itself if the eyeshield varies substantially in thickness over small areas. Polycarbonate resin's characteristics of duplicating the mold surface will cause distortion if the mold surface is less than "perfect".

A test for distortion will also reveal imperfections not visible to the unaided eye nor revealed by other tests. These imperfections include surface scratches, pits and entrapped foreign bodies.

8. Summary

Production quantities of optically transparent polycarbonate lenses can be manufactured with a great deal of reliability by injection-molding processes. The eyeshield for the U. S. Army Flyer's helmet is produced in this manner.

The mold used was end-gated and was highly polished. Of three available grades of resin, the material with the lowest molecular viscosity provided the best results.

Injection-molding of polycarbonate lenses employs standard equipment and techniques. These, however, must be adjusted to account for the idiosyncrasies of the resin, e.g., hygroscopic and flow characteristics.

The development molds produced about 75,000 acceptable eyeshields which were made available to U. S. Army and Air Force airmen for immediate tactical use.

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Figure 7. Three basic operations required to fabricate the
polycarbonate eyeshield are shown in stages:

    a. Molding Operation
    b. Removal of sprue by mold operator
    c. Removal of gate and flash to finish
       the eyeshield

9. <u>References</u>

1. Coates, S. B., Jr., and J. D. Beyer, <u>Wound Ballistics</u>, Office of The Surgeon General, Department of the Army, 1962

2. Balint, R. D., <u>Mold Finishing</u>, SPE Journal, March, 1966

3. Schettig, J. R., <u>How to Select Mold Steels, Plastic Technology</u>

4. Military Standard, MIL-STD-662A, 15 June 1964, <u>Ballistic Acceptance Test Method for Personal Armor Material</u>

5. Military Specification, MIL-V-22272B(WP), 28 January 1965, <u>Visors, Protective Helmet</u>

6. Military Specification, MIL-I-38169 (USAF), 26 March 1963, <u>General Specification for Lenses, Goggle and Visor, Helmet, Optical Characteristics</u>

7. Military Specification, MIL-V-43511(GL), 30 June 1967 and Amendment-2, 13 May 1968, <u>Visors, Flying Helmet, Polycarbonate</u>

8. United States of America Standard Institute, Standard Z2.1-1959 <u>Head, Eye, and Respiratory Protection</u>

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
U.S. Army Natick Laboratories Natick, Massachusetts 01760	UNCLASSIFIED
	2b. GROUP

3. REPORT TITLE

DEVELOPMENT AND FABRICATION OF A POLYCARBONATE EYESHIELD FOR THE U. S. ARMY FLYER'S HELMET

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report

5. AUTHOR(S) (First name, middle initial, last name)

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6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1970	20	8

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
DA19-129-AMC-332	
b. PROJECT NO.	71-3-CE (C&PLSEL-76)
1J664713D547	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U. S. Army Natick Laboratories Natick, Massachusetts 01760

13. ABSTRACT

The need to provide U.S. Army aircrewmen with increased eye protection saw a production technique developed to make optically acceptable, shatter- and impact-resistant eyeshields from polycarbonate resin. It was found that production quantities of optically transparent polycarbonate lenses can be manufactured with a great deal of reliability by injection-molding processes. Injection-molding of polycarbonate lenses employs standard equipment and techniques. These, however, must be adjusted to account for the idiosyncrasies of the resin, e.g., hygroscopic and flow characteristics.

In this fabrication project, the mold used was end-gated and highly polished. Of three available grades of resin, the material with the lowest molecular viscosity provided the best results. The development molds produced about 75,000 acceptable eyeshields which were made available to U.S. Army and Air Force airmen for immediate tactical use.

The polycarbonate resin characteristics and molding techniques that influenced the design of the eyeshield, and the development of the fabrication technique are discussed. Also discussed are factors that governed the selection of material type, mold design, and quality assurance considerations.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	W1	ROLE	WT	ROLE	WT
Design	8					
Fabrication	8		4,9			
Eye shield	9		9		9	
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